Physics IA: The effect of cup thickness on cooling time of hot water.

Introduction:

I noticed when people get coffee, they put another cup on top of the other. This made me wonder how effective this was at keeping your coffee warm.

Theory:

Temperature is a property that determines the direction of thermal energy transfer between two bodies in thermal contact and measures the average kinetic energy of the molecules of a substance. Heat (the change in thermal energy) is transferred – the object heats the air around it, causing the air molecules to move and make contact with cooler objects then transfer heat to them. This is the process of convection. The total heat lost will be the sum of the heat lost from the top of the cup and the heat lost from the sides. The heat loss from the top will be constant for all points as the same surface area and same temperature of water are used for each point; the heat loss from the base will be negligible as the heat mat on the bottom prevents this; only the heat loss from the sides will change and shall be measured. This heat loss will depend on the level of insulation provided and the temperature gradient.

Insulation traps the air particles, which are a poor conductor of heat, to prevent circulation and convectional currents and thus the transfer of heat energy is reduced, keeping the heat energy within the object insulated. Insulating materials have a low temperature gradient (the difference between the temperature of the water and air divided by the thickness). The rate of cooling is expected to depend on temperature gradient therefore I am able to predict that the time to cool will have a positive correlation to thickness.

As thickness increases, the heat loss from the sides will lessen, as the time to cool will be a positive function of thickness. Eventually, thickness will be negligible, as the top will dominate heat loss – the curve will even out to a fixed time length. This is unlikely to be reached due to the limitations of the way the cups are stacked in this experiment to only eight because of time constraints, so the thickness is unable to keep increasing. The y intercept will show the length of time if there were no sides so shows the constant cooling time from the top. The gradient will show the affect of the cup thickness on cooling time.

Preliminary Investigation:

Starting Temperature – as it would be near impossible to be able to start the investigation at 100°C (boiling temperature), a realistic starting temperature was found at 80°C by measuring the temperature of the water once it was poured into a cup rounded down to the nearest 10.

End Temperature – as it was hypothesised that additional cups would cause a slower cooling time, a suitable temperature to measure the time of cooling to was found so as to make timing more reasonable. I decided to measure to the next lowest 10 at 70°C as any lower would be too time consuming and I wanted to collect enough data to draw a reasonable conclusion in the available time.

Uncertainties – as it was difficult to measure the exact time at which the temperature decreased, it was measured how long the temperature appeared to be at a degree (80°C was chosen) to see what time limit may be missed. This was done by carefully timing how long it took for the water to appear to move into and from the indicator of 80°C on the thermometer. This measurement uncertainty on time was estimated to be 5 seconds.

Method

The purpose of the investigation is to see what effect insulation has on temperature change. This was done by using paper cups. A heat mat was put under the cups as a safety precaution and to minimise heat escaping from the base. A kettle was used to boil the water which was then measured to 100ml using a measuring cylinder. This was immediately poured into the cup and its temperature was measured using a thermometer. When the thermometer read that the water had reached 80°C, the stopwatch was started and was then stopped when the thermometer read it had reached 70°C. This was repeated for different thickness levels of insulation by stacking the cups up to eight times. Each level of insulation was repeated three times. As the researcher was dealing with hot water temperatures, a heat mat was used for the dual purpose of limiting the heat loss from the base of the cup, and to provide safety to the researcher so that if the cups were to spill the hot water, the heat mat would slow the water down through its absorption of it more so than the bench surface. Moreover, the researcher remained standing so as to be able to move out of the way if the water was to spill and held the cups carefully when filling them, wearing safety gloves to protect their hands from burning if the water was to spill onto them.

Experimental Variables:

Independent Variable: the level of insulation by the thickness of the cup. The thickness was increased by stacking gradually more and more cups (up to eight cups).

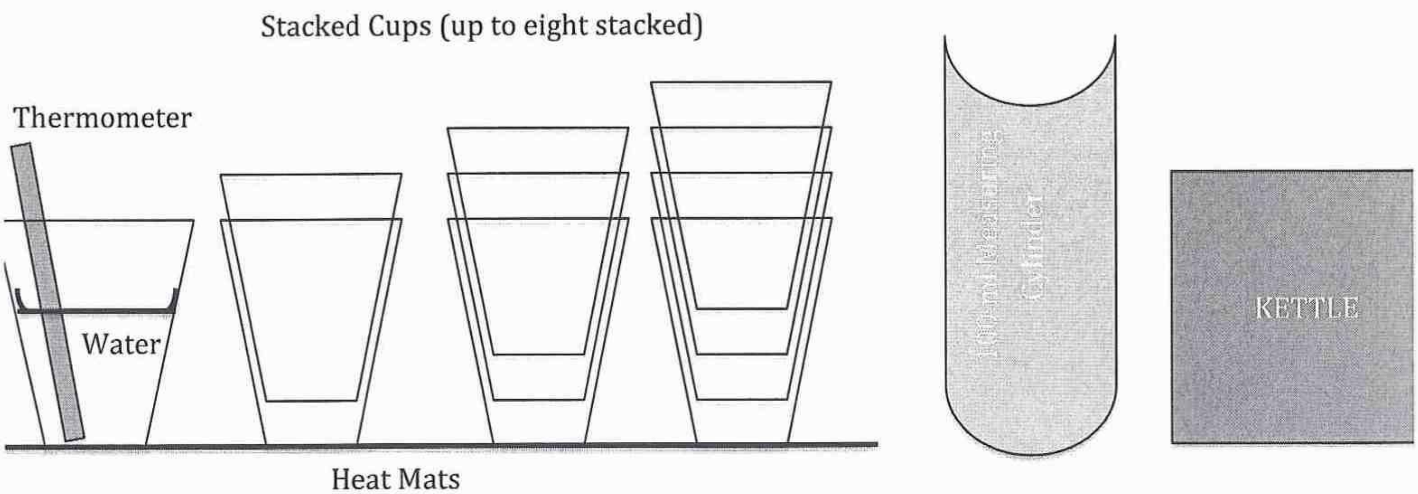
Dependent Variable: the time it took for the water's temperature to decrease from 80°C to 70°C.

Controlled Variables: the amount of time the water stayed at one degree was measured in order to have an accurate uncertainty level. All the cups were identical and had the same amount of water (100ml) poured into them using a measuring cylinder so as they would have equal volume and surface area and they were each stirred with the thermometer the same amount of times (5 times) so as to get a more accurate starting temperature measurement, all of which would have an effect cooling time.

Uncontrolled Variables: The room temperature was measured and all cups were kept at the same area of the room to avoid different air currents affecting the experiment and extra insulation of the water from warmer surrounding air and were monitored using a thermometer. This minimised the effects of a difference in temperature and, because there was on each day of the experiment, every data point was measured on each day. To minimise a difference in air gap between the stacked cups for each repeated measurement, which would have provided extra insulation, they were forced down onto each other. The air gap was determined by using a micrometre to measure the thickness

of a single cup and up to four stacked cups and then an equation was used to solve for the air gap between each pair of cups, which was assumed to remain constant.

Equipment:



Stacked Cups (up to eight stacked)
Thermometer
Water
Heat Mats
100ml Measuring
Cylinder
KETTLE

Results

Raw Data:

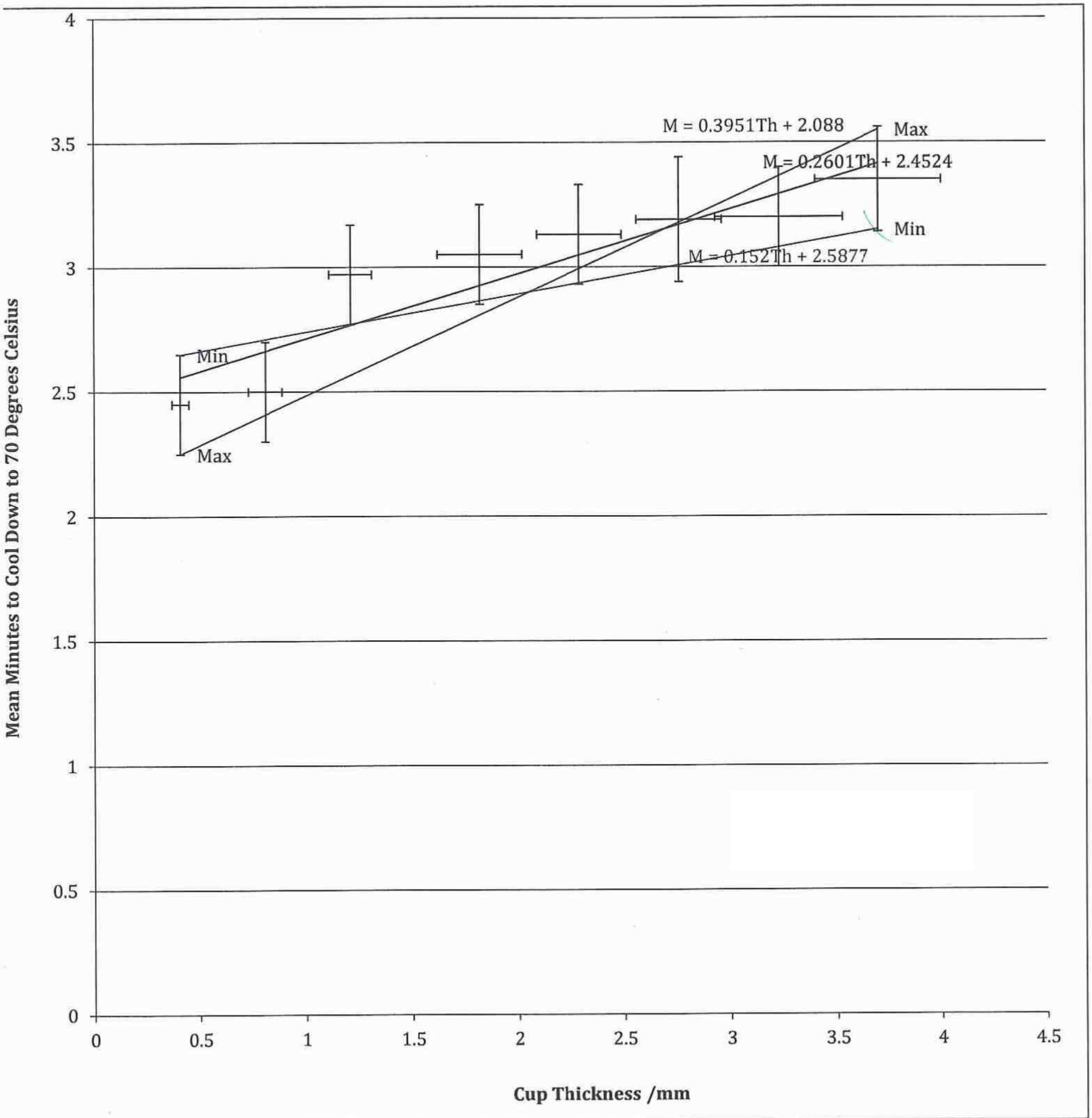
Number of Cups, N ± 0 cups	Time taken for water temperature to fall from 80°C to 70°C, t/minutes ±0.2 minutes		
1	2.5	2.3	2.7
2	2.2	2.7	2.7
3	3.0	3.0	2.9
4	3.1	3.2	3.2
5	3.0	3.2	3.3
6	3.1	3.0	3.5
7	3.3	3.2	3.2
8	3.1	3.4	3.5

Processed Data:

Thickness of Cup, Th/mm	Uncertainties/mm	Average time taken for water temperature to fall from 80°C to 70°C/minutes	Uncertainties/minutes
0.41	0.04	2.5	0.2
0.81	0.08	2.5	0.2
1.2	0.1	3.0	0.2
1.8	0.2	3.1	0.2
2.3	0.2	3.1	0.2
2.8	0.2	3.2	0.3
3.2	0.3	3.2	0.2
3.7	0.3	3.4	0.2

Equations in Appendices

A Graph to Show the Effect of Cup Thickness on Cooling Temperature of Water



Conclusion

In conclusion, the experiment shows that there is a positive relationship between thickness of insulation and cooling temperature of hot water as each point touches the line of best fit and it is a straight correlational curve. It however does not touch the origin, as even with no insulation, it would still take time for the water's temperature to fall. This is only valid for the decrease of ten degrees from 80 to 70 degrees Celsius as the experiment only showed this temperature range because of time limitations, and is only valid for a thickness of up to 3.7mm of insulation and this insulating material.

Evaluation:

The controlled variable of the water's volume may have had an effect on creating a large range in data. As the experiment required speed to transfer the hot water to the cup before reaching 80 degrees Celsius, it left room for human error. Using a measuring cylinder meant less accuracy in the measurement of the water as it was difficult to get the water level exactly at 100ml and so there may have been (minute) differences in the water's volume, which would have increased cooling time. This could be improved by using a more accurate form of measurement such as a burette to provide an exact amount of water every time, however this would be impractical as too much cooling would occur to provide usable results.

The air gap between the cups meant that there was extra insulation provided not from the insulating material being measured and there may have been differences in the repetitions of thickness and air gaps, both of which were difficult to measure accurately. This could be improved by wrapping material around a cup tightly to avoid an air gap occurring and to have more control on the thickness of insulation provided. However, the size of the air gap in this experiment was negligible, and was measured and taken into account to the best of my ability. Moreover, the cups were stacked as tightly as possible so that there was no measurable air gap in the first four data points.

The range of data is limiting as it does not give an accurate representation of the cooling time of hot water – it is limited to showing the time to reach 70 degrees Celsius and there may be significant time changes as the temperature decreases, as it may not follow a completely proportional pattern. The repeated readings have a fairly large range between them, making them less precise. This lessens the quality of data as the average value found may be anomalous. This could be improved by taking more readings using more accurate measuring equipment, such as a digital thermometer connected to a computer taking readings 10 times a second to get a precise reading for when the end temperature is reached and timing this exactly – this was not done due to time restrictions and equipment available. The level of precise uncertainties did however help this as they allow every point to touch the line of best fit, meaning that there is a relationship between the variables despite anomalous data.

To get precise readings of temperature would have been time consuming, as the thermometers would have had to be watched carefully each time. Therefore, this reduces the accuracy of the readings. However, the uncertainty of the time window that may have been missed was measured fairly accurately, which increases the validity of the results so that a conclusion can be drawn fairly confidently so this is not a significant weakness.

The cup thickness of 2.76mm left the largest uncertainty, making it an unreliable result and therefore may be discarded as an anomaly but has been kept because it still touches the line of best fit and follows the trend. This could be made more reliable by repeating more measurements and discarding any anomalies. The rest of the data points were under the average uncertainty level of 0.2min or just over (0.21min at 3.70mm thickness), which suggests that the data may be accepted to be a reliable presentation of the relationship between the two variables.

Appendices

Equations for Averages of Cooling Times:

(2.5+2.3+2.7)/3=2.5

(2.2+2.7+2.7)/3=2.5

(3.0+3.0+2.9)/3=3.0

(3.1+3.2+3.2)/3=3.1

(3.0+3.2+3.3)/3=3.1

(3.1+3.0+3.5)/3=3.2

(3.3+3.2+3.2)/3=3.2

(3.1+3.4+3.5)/3=3.4

Cup Thickness:

Number of Cups	Thickness/mm		
1	0.38	0.40	0.45
2	0.79	0.85	0.80
3	1.25	1.19	1.18
4	1.85	1.75	1.85

Average Thickness:

(0.38+0.40+0.45)/3=0.41

(0.79+0.85+0.80)/3=0.81

(1.25+1.19+1.18)/3=1.21

(1.85+1.75+1.85)/3=1.82

From this information, an equation can be made:

Number of cups + air gap = Thickness → c +a = Th

c = 0.41

This can then be used to determine the air gap present using the middle data point as there is no air gap present in the first three points:

(4 x 0.41) + 3a = 1.82

3a = 0.18

a = 0.06

Which can then be used to find the thickness of all data points:

(5 x 0.41) + (4 x 0.06) = 2.29

(6 x 0.41) + (5 x 0.06) = 2.76

(7 x 0.41) + (6 x 0.06) = 3.23

(8 x 0.41) + (7 x 0.06) = 3.70

(2 x 0.41) + 0.06 = 0.88 > 0.81, therefore there is no air gap

(3 x 0.41) + (2 x 0.06) = 1.35 > 1.21

Uncertainties:

0.45-0.38=0.7/2=0.035 → 0.04mm which would then be added for every cup added and rounded to 2 significant figures

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4/ICCS

Group 4: Individual candidate cover sheet (biology, chemistry and physics)

Arrival date: **20 April / 20 October**

Session: May 2016

School number:

School name:

- *Complete this form in the working language of your school (English, French, Spanish).*
- *The form must be completed by the teacher and candidate.*
- *A completed copy should be retained by the school.*

Subject: Physics

Level: SL

Candidate name:

Session number:

Candidate section:

To be completed by the candidate.

Title of the group 4 project: Light

Write a reflective statement of about 50 words outlining your involvement in the group 4 project:

I contributed by helping with the physics experiment as I take physics standard. I helped my group set up the experiment and I recorded the refracted light coming out of the prism. Once recorded, I worked out the refractive index so they could be recorded. I also contributed to making of the poster as I had lots of free time waiting for my experiment. I enjoyed working collaboratively with my group and getting to know people I otherwise wouldn't interact with better, especially as we had some new people in our group. I enjoyed my day and found it interesting to learn more about the sciences I don't do. Overall, it was a fun day!

Title of individual investigation: The effect of cup thickness on cooling time of hot water.